MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.2-DN-B0205-08

SONIC BOOM RESULTS FOR A NOMINAL MISSION 3B

ENGINEERING SYSTEMS ANALYSIS

10 JUNE 1975

This Design Note is submitted to NASA Under Task Order B0205, Subtask (Integrated Entry Systems) in fulfillment of Contract NAS 9-13970

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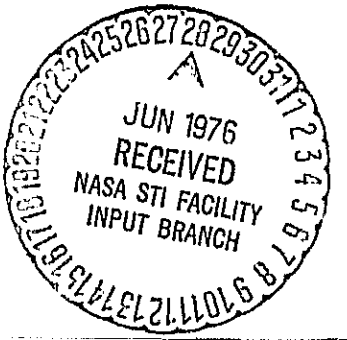

1.0 SUMMARY

This design note documents the results obtained in the analysis of the effects of sonic boom overpressures at ground level for a nominal Mission 3B with the current baseline guidance. These results are in the form of ground level overpressures generated along the groundtrack out to lateral cutoff from Mach 3.0-1.10 at 0.10 (tenth) Mach intervals.

Some of the predicted overpressures are in excess of the Environment Impact Statement (Ref. A, p. 18) which states "Return trajectories will be controlled to avoid increases or focusing above this level (2.0 psf) over land." Preliminary trajectory constraints which will reduce excess sonic boom overpressures to approximately 2.0 PSF are included.

This analysis work was conducted under Contract Number NAS 9-13970 Task Order B0205.

2.0 INTRODUCTION

The sonic boom analysis is oriented toward determining the groundlevel overpressures generated by nominal and off-nominal baseline missions, aborts, and OFT's. These studies are being coordinated with the NASA-wide Sonic Boom Working Panel and will be presented in detail in a report published by them this year. The analysis employs an expanded version (Ref. B) of the Thomas Waveform Parameter Method computer program (Ref. C) to generate sonic boom overpressures along the groundtrack and out

to the lateral cutoff. This program was selected by the panel as the most accurate for evaluating sonic boom overpressures. The input data which the program needs are obtained from ENTRY and TAEM trajectory simulations.

3.0 DISCUSSION

The sonic boom overpressures are generated by the Thomas program which uses the waveform parameter method. This method extrapolates nearfield pressure signatures to the far-field (ground). The sonic boom overpressure signature data base is a collection of the results from wind tunnel tests in which near-field pressure signatures are measured for specific combinations of Mach, angle of attack and bank angle. The program interpolates as required for conditions not included in the data base. The extent of the current data base is presented in Figure 1. The flight conditions for Mission 3B are shown in Figure 2. It is observed that in the TAEM region the flight angle of attack profile is lower than that of the wind tunnel signature data base. This will result in conservative estimates of the overpressure level in these cases. Similar data base-flight condition compatibility problems exist in ENTRY but the differences are expected to be insignificant The data base will be enlarged later this year to include a more complete angle of attack, bank angle, and Mach number matrix.

The trajectory data used to generate the results for this analysis were taken from two different flight simulation programs. The flight conditions for the ENTRY portion (Mach 3.0-1.6) were

SONIC BOOM DATA BASE
ORBITER 040A

ANGLE OF ATTACK DEG.	MACH NUMBER				
	1.3	1.64	2.21	2.61	3.02
10	▨	▨	▨	▨	
25				▨	▨

NOMINAL ROLL ANGLE SCHEDULE:
DEGREES -0, 30, 60, 90, 120, 150, 180

FIGURE 1

40/30 NOMINAL 3B MISSION
FLIGHT CONDITIONS FOR SONIC BOOM ANALYSIS

ENTRY

I.C.'s	#1	#2	#3	#4	#5
Title	No. 1 2.99	No. 2 2.89	No. 3 2.79	No. 4 2.69	No. 5 2.59
MACH	2.99238	2.8946	2.7948	2.6934	2.5913
Altitude	91226.5	89554.3	87922.8	86357.3	84864.1
M dot	-.01612	-.01648	-.01681	-.01698	-.01704
Azimuth dot	-.39444	-.40592	-.41430	-.42978	-.45288
Gamma dot	-.02587	-.00982	.00438	.00838	.00154
Gamma	-5.2771	-5.3901	-5.4014	-5.3583	-5.3245
Longitude	-120.66	-120.65	-120.64	-120.619	-120.601
Latitude	35.5778	35.5317	35.4877	35.4458	35.406
Azimuth	168.112	165.701	163.245	160.7147	158.0675
Bank	-34.520	-33.703	-32.584	-32.321	-32.828
Alpha	14.5562	14.2518	13.9419	13.6276	13.3113

ENTRY

I.C.'s	#6	#7	#8	#9	#10
Title	No. 6 2.49	No. 7 2.39	No. 8 2.29	No. 9 2.19	No. 10 2.10
MACH	2.4896	2.3885	2.2877	2.1901	2.0988
Altitude	83433.1	82096.1	80955.3	79871.1	78627.1
M dot	-.01687	-.01685	-.01667	-.01578	-.01467
Azimuth dot	-.44542	-.08092	.38099	.62538	.62568
Gamma dot	.00789	.11839	.01671	-.17488	-.19470
Gamma	-5.3350	-4.9207	-4.3849	-4.9652	-6.0809
Longitude	-120.58	-120.56	-120.54	-120.52	-120.51
Latitude	35.3687	35.3336	35.3000	35.2673	35.2352
Azimuth	155.307	153.561	154.473	157.718	161.473
Bank	-31.185	-5.6853	24.3147	42.8679	42.1171
Alpha	12.9960	12.6839	12.3737	12.0701	11.7888

FIGURE 2

40/30 NOMINAL 3B MISSION
FLIGHT CONDITIONS FOR SONIC BOOM ANALYSIS

ENTRY

I.C.'S	#11	#12	#13	#14	#15
Title	No. 11 2.01	No. 12 1.90	No. 13 1.80	No. 14 1.70	No. 15 1.61
MACH	2.0136	1.9059	1.8000	1.6938	1.6112
Altitude	77192.1	74997.1	72581.1	70160.9	68519.7
M dot	-.01376	-.01323	-.01314	-.01362	-.01374
Azimuth dot	.62824	.64393	.62899	-.02987	-.63458
Gamma dot	-.20527	-.17395	-.10803	.10179	-.06943
Gamma	-7.2829	-8.8447	-10.006	-9.8448	-9.6117
Longitude	-120.49	-120.48	-120.48	-120.48	-120.47
Latitude	35.2038	35.1634	35.1248	35.0882	35.0623
Azimuth	165.232	170.3419	175.481	178.2856	176.2086
Bank	41.055	38.803	33.907	-1.5928	-30.266
Alpha	11.5160	11.1807	10.8547	10.5289	10.2775

TAEM

I.C.'s	#16	#17	#18	#19	#20
Title	No. 16 1.50	No. 17 1.40	No. 18 1.30	No. 19 1.20	No. 20 1.10
MACH	1.49421	1.40343	1.29765	1.19492	1.10132
Altitude	65784.8	61432.4	56462.3	52568.2	48984.2
M dot	-.00803	-.00782	-.00983	-.01029	-.00857
Azimuth dot	-.09347	-.16794	-.17097	-.08488	-.04699
Gamma dot	-.51425	-.24305	-.00437	-.01636	.033113
Gamma	-11.675	-17.272	-18.713	-18.611	-18.623
Longitude	-120.47	-120.46	-120.45	-120.44	-120.43
Latitude	34.8422	34.7984	34.7585	34.7281	34.7002
Azimuth	171.140	168.992	167.006	165.804	165.101
Bank	-13.220	-10.276	-6.043	-3.4774	-1.9310
Alpha	4.92926	5.82151	6.36659	5.76146	5.77432

FIGURE 2 (CONTINUED)

obtained from a SVDS (Space Vehicle Dynamic Simulator) nominal Mission 3B entry trajectory supplied by J. Harpold (NASA-FM) using the Dec. '74 ADC guidance with the baseline 40/30 α-profile. The data for the TAEM region analyzed (Mach 1.5-1.10) were generated by D. Cooke (NASA-EX) using the SSFS (Space Shuttle Functional Simulator) program with ACS 15, Aero 22 and the guidance from the Nov. '74 RI FSSR.

The Thomas program specifies eight major parameters in the calculation and location of ground level overpressures. A list of these parameters (i.e. Mach, altitude, gamma, longitude, latitude, azimuth, bank, alpha, and the time derivatives of Mach, azimuth, and gamma) is presented in Figure 2, along with the corresponding values for the nominal Mission 3B. The overpressures are calculated in increments specified by the user for each set of conditions. The increment is measured in degrees as the ray angle (phi), the lateral angle in degrees corresponding to the input pressure signature and aircraft bank angle as shown in Figure 3.

The output at each phi angle for a specific set of flight conditions gives the angle of the ray, the initial waveform and the waveform at the ground, the wave arrival time, the longitude and latitude of the ray's intersection with the ground and that position relative to the distance from the groundtrack in nautical miles. The maximum overpressure at ground level for a specific ray is given in PSF (lbs./sq.ft.). These parameters

LATERAL RAY ANGLE (PHI) NOMENCLATURE

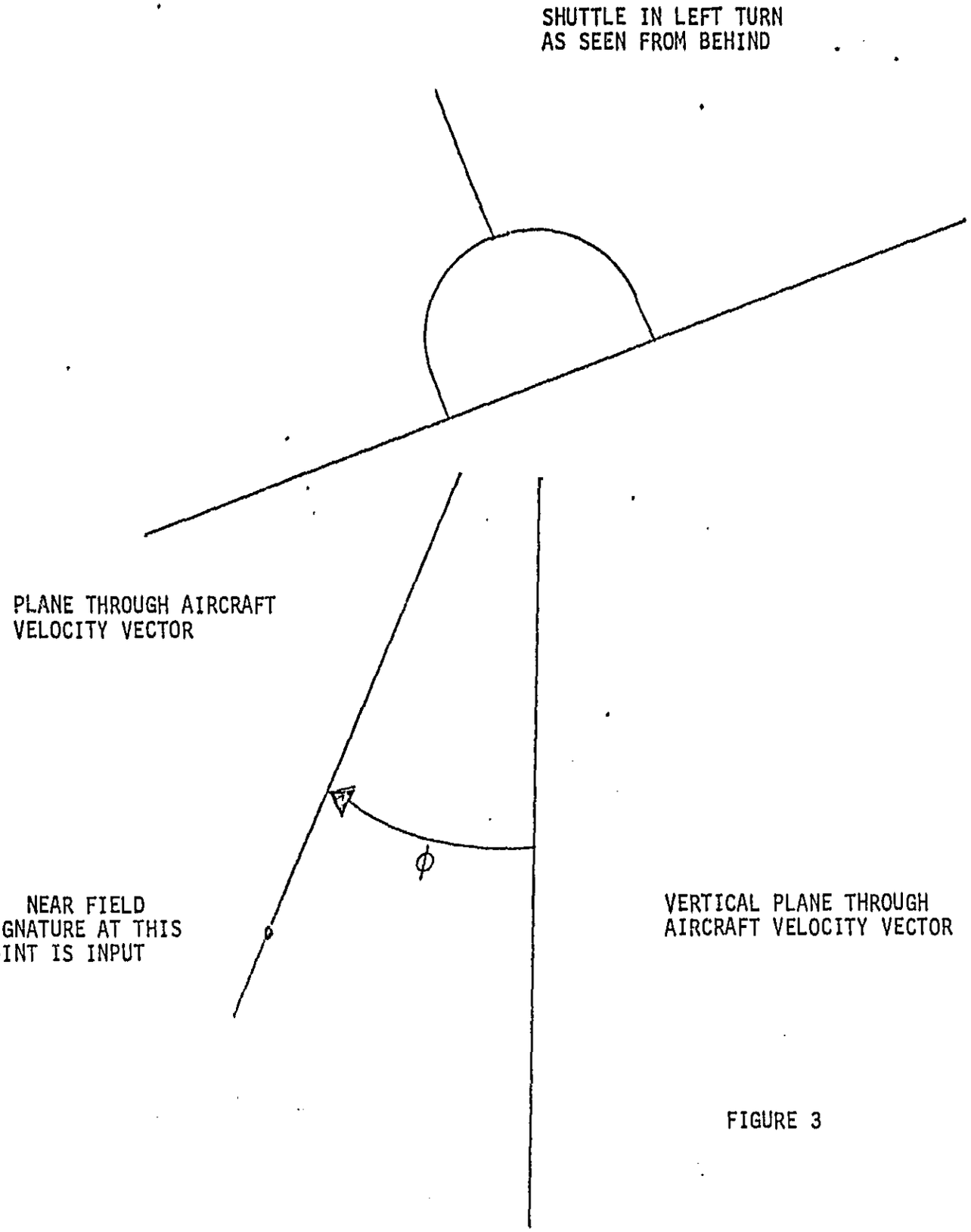

FIGURE 3

PHI is measured from the vertical plane passing through the aircraft velocity vector. Positive values of PHI correspond to rays that start out to the left of vertical, as seen from behind the aircraft.

are output for each flight condition out to lateral cutoff (the point at which sonic rays no longer reach ground level).

4.0 RESULTS

Figure 4 shows the ground track for the nominal Mission 3B in the Mach 3.0 to 1.10 region. A 2 PSF isobar has been identified enclosing the region effected by overpressure levels of 2 PSF or greater. The sonic boom ground level overpressure results for each Mach number analyzed are presented in Figure 5. There is a sharp increase in groundtrack overpressures in the TAEM region. The rise in overpressure level is due to the discontinuity at the TAEM interface depicted in Figure 6. The discontinuity results from a change in the guidance schemes from ENTRY to TAEM. The ENTRY region flies a reference drag profile while the TAEM guidance flies a reference dynamic pressure level which is higher at the interface than that resulting from the ENTRY guidance. This change commands a large pitch down maneuver which results in a large negative gamma dot that significantly increases groundtrack overpressure levels.

There are flight conditions which also produce rising overpressures near lateral cutoff in both ENTRY and TAEM. This phenomenon occurs when large azimuth rates are induced in response to bank angle guidance commands (Figure 6). The sonic boom rays are compressed together on the inside of the turn increasing the

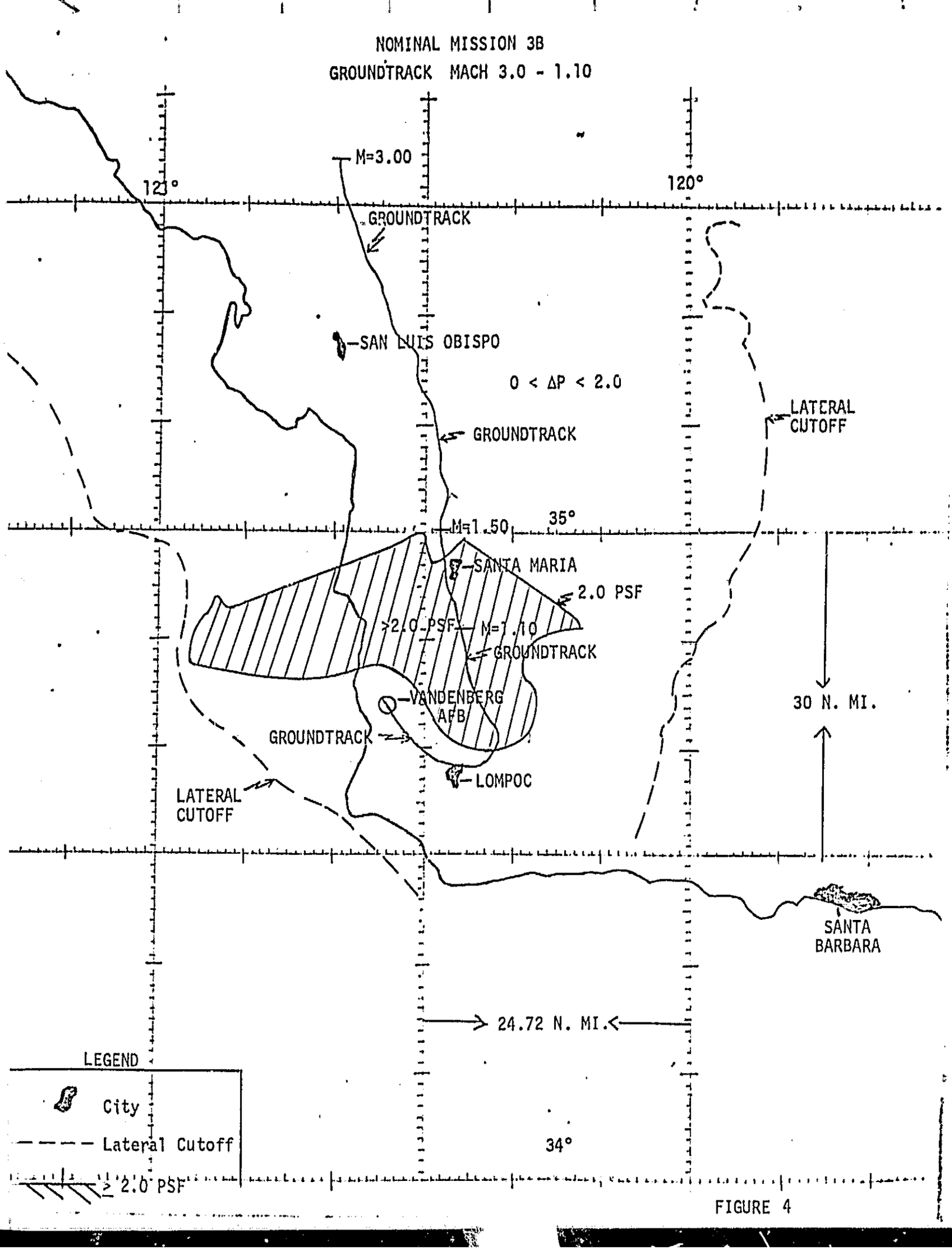
NOMINAL MISSION 3B
GROUNDTRACK MACH 3.0 - 1.10
M=3.00
GROUNDTRACK
120°
SAN LUIS OBISPO
0 < ΔP < 2.0
LATERAL CUTOFF
GROUNDTRACK
35°
M=1.50
SANTA MARIA
2.0 PSF
>2.0 PSF
M=1.10
GROUNDTRACK
VANDENBERG AFB
30 N. MI.
GROUNDTRACK
LOMPOC
LATERAL CUTOFF
SANTA BARBARA
24.72 N. MI.
LEGEND
City
Lateral Cutoff
≥ 2.0 PSF
34°

FIGURE 4

NOMINAL MISSION 3B
GROUND LEVEL OVERPRESSURES

MACH NUMBER	ONE DEGREE FROM CUTOFF(-)	Δφ -60°	Δφ -40°	Δφ -20°	GROUND-TRACK Δφ = 0°	Δφ 20°	Δφ 40°	Δφ 60°	ONE DEGREE FROM CUTOFF(+)
ENTRY 3.00	-62° / .783	.865	1.259	1.445	1.429	1.189	.954	.746	62° / .729
2.90	-61° / .839	.874	1.287	1.490	1.487	1.251	1.003	.782	61° / .773
2.80	-61° / .840	.881	1.315	1.538	1.548	1.318	1.056	.818	61° / .807
2.70	-61° / .835	.887	1.347	1.584	1.605	1.381	1.111	.859	61° / .847
2.60	-61° / .815	.887	1.378	1.627	1.652	1.434	1.163	.907	61° / .894
2.50	-60° / .870	.870	1.389	1.656	1.686	1.464	1.183	.916	60° / .916
2.40	-60° / .792	.792	1.337	1.665	1.782	1.602	1.228	.741	60° / .741
2.30	-59° / .967	-	1.256	1.556	1.733	1.675	1.314	-	59° / .780
2.20	-59.35° / 2.233	-	1.400	1.529	1.665	1.634	1.365	-	59° / .794
2.10	-59.55° / 3.110	-	1.475	1.590	1.720	1.676	1.390	-	59° / .810
2.00	-60°+ / RTA->0	5.594	1.549	1.658	1.785	1.719	1.421	.734	60° / .734
1.90	-60.15° / 5.519	3.671	1.613	1.733	1.857	1.762	1.439	.761	60° / .761
1.80	-60.20° / 2.013	1.905	1.622	1.802	1.931	1.805	1.436	.753	60° / .753
1.70	-59° / .817	-	1.441	1.833	2.001	1.800	1.384	-	59° / .770
1.60	-58° / .793	-	1.424	1.818	1.956	1.814	1.557	-	58° / 1.342
TAEM 1.50	-58° / 1.380	-	2.399	3.209	3.404	3.030	2.299	-	58° / 1.382
1.40	-62° / 1.066	1.216	2.101	2.819	3.038	2.683	2.117	1.280	62° / 1.134
1.30	-63° / .923	1.106	1.831	2.477	2.769	2.361	1.855	1.131	63° / .938
1.20	-62° / .947	1.099	1.887	2.545	2.921	2.450	1.864	1.071	62° / .913
1.10	-58° / .926	-	1.730	2.339	2.730	2.281	1.704	-	58° / .900

Δφ = 20 DEG. (INCREMENT SPECIFIED)

OVERPRESSURES ARE IN PSF (LBS/SQ. FT.)

*RTA->0 RAY TUBE AREA GOES TO ZERO. FOCUSING OCCURS

FIGURE 5

ORIGINAL PAGE IS
OF POOR QUALITY

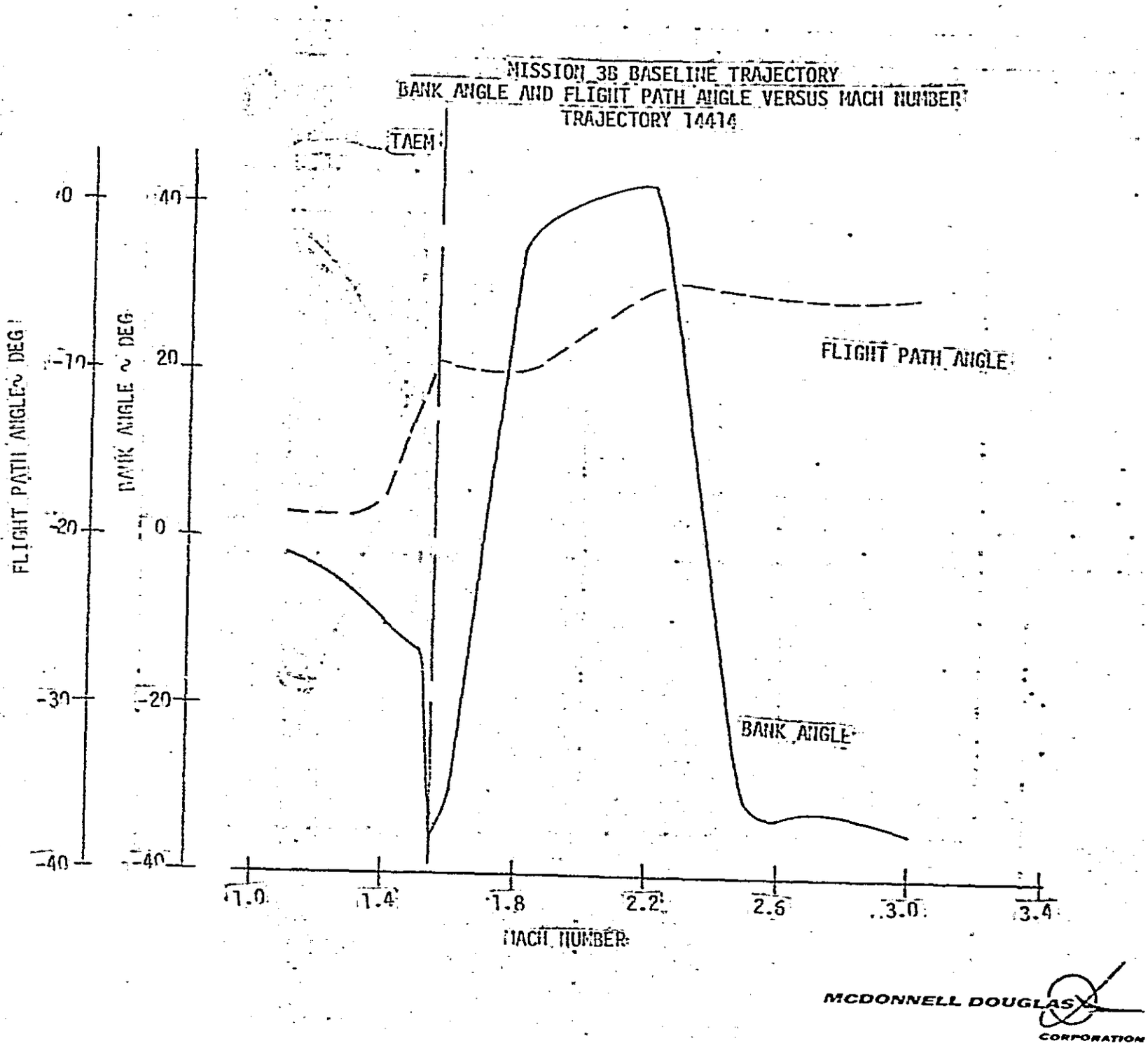

FIGURE 6

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overpressure level. This occurs nominally in ENTRY and is especially evident in the TAEM region when S-turns are required to dissipate excess range.

Flight boundaries have been generated to aid in the evaluation of flight techniques to reduce overpressures levels so that they are more nearly compatible with the Environmental Impact Statement. Figures 7 and 8 present the preliminary results of this activity. The orbiter must remain above the h-v boundary or below the h-$\bar{q}$ boundary. The additional constraints on gamma dot (> -0.30 deg/sec) and azimuth dot (absolute value < 0.55 deg/sec) are also required.

5.0 CONCLUSIONS

The results of the current nominal Mission 3B (RI 14074) show that there are overpressures in excess of the Environmental Impact Statement (i.e. 2.0 PSF). Further analysis will be conducted to determine the effects of crossrange, temperature inversions, off-nominal missions, aborts, and updated trajectories as they become baselined. It should be emphasized that the boundaries presented are preliminary and may be altered as additional data become available. They have been established to serve only as a guideline for reducing the excess sonic boom overpressure levels to around 2.0 PSF. New wind tunnel signature data scheduled to be obtained this summer to enlarge the data base are required before a detailed evaluation of overpressure level versus performance penalty can be conducted.

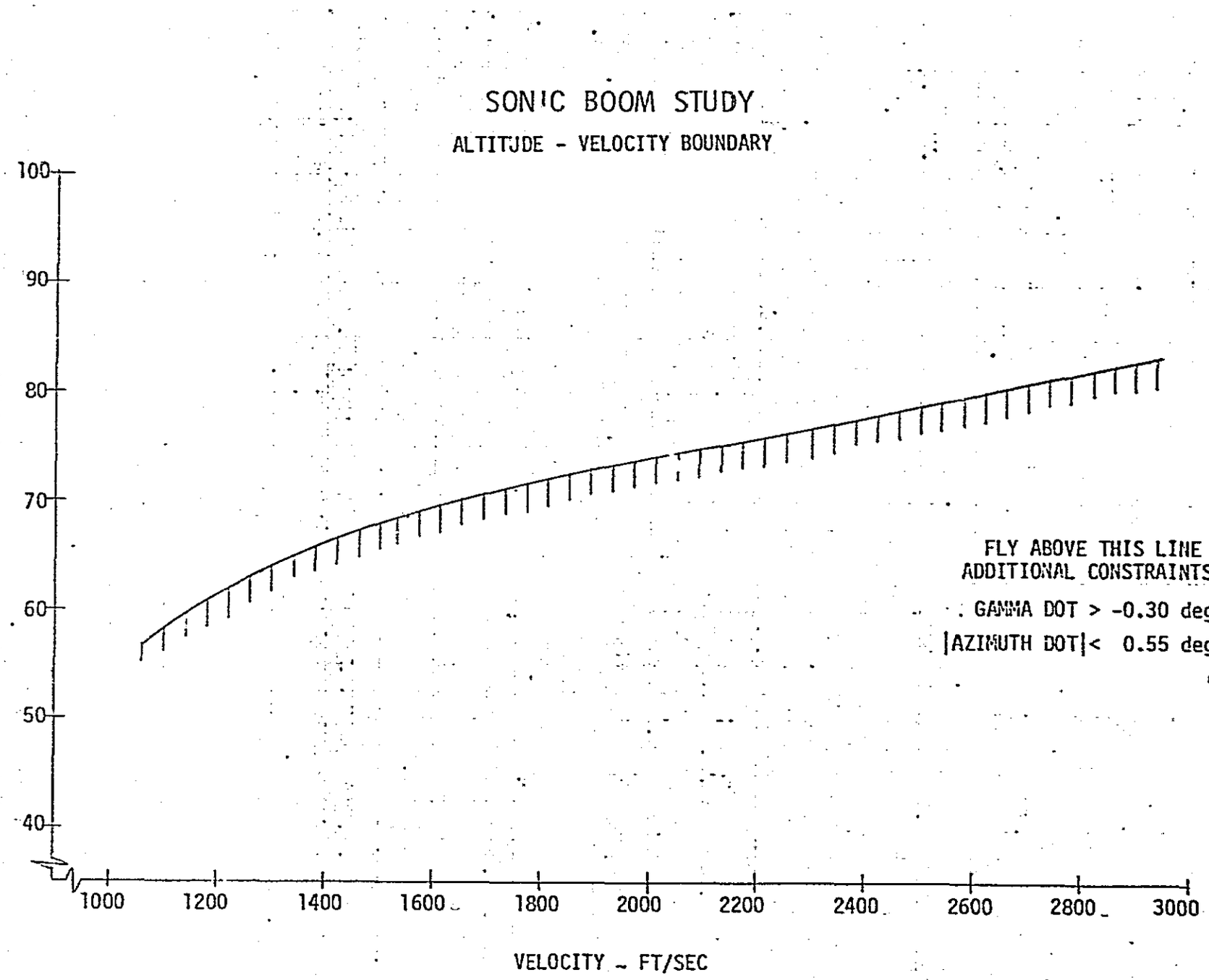
SONIC BOOM STUDY
ALTITJDE - VELOCITY BOUNDARY
ALTITUDE - 10K FT.
100
90
80
70
60
50
40
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
VELOCITY - FT/SEC
FLY ABOVE THIS LINE
ADDITIONAL CONSTRAINTS
GAMMA DOT > -0.30 deg/sec
|AZIMUTH DOT|< 0.55 deg/sec

FIGURE 7

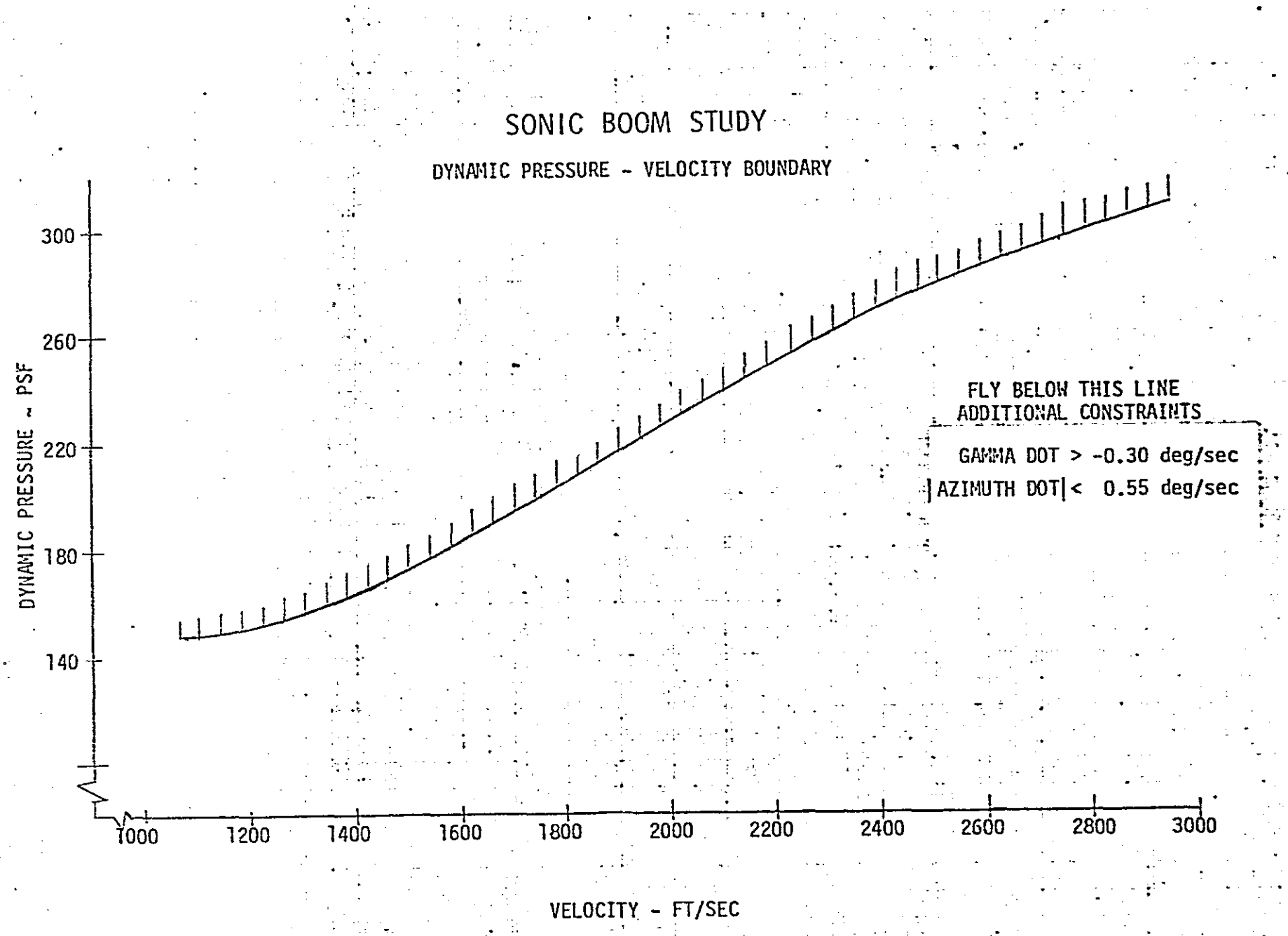
SONIC BOOM STUDY
DYNAMIC PRESSURE - VELOCITY BOUNDARY
DYNAMIC PRESSURE - PSF
300
260
220
180
140
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
VELOCITY - FT/SEC
FLY BELOW THIS LINE
ADDITIONAL CONSTRAINTS
GAMMA DOT > -0.30 deg/sec
|AZIMUTH DOT| < 0.55 deg/sec

FIGURE 8

6.0 REFERENCES

A. Environmental Statement for the Space Shuttle Program, Final Statement, July 1972, NASA, Washington, D.C.

B. Expanded Versions of the Ames Research Center Sonic Boom Extrapolation Program, Boeing Co. Memo 5-2581-HOU-086, June 9, 1972.

C. Extrapolation of Sonic Boom Pressure Signatures by the Waveform Parameter Method, by Charles Thomas, Ames Research Center, NASA TN D-6832.